

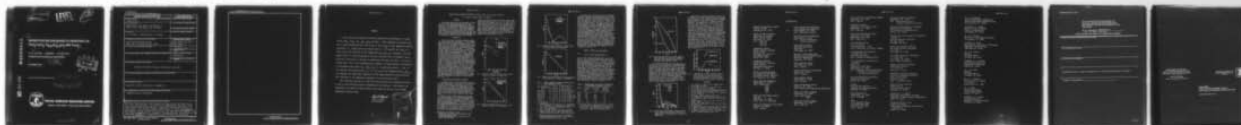
AD-A068 615

NAVAL SURFACE WEAPONS CENTER WHITE OAK LAB SILVER SP--ETC F/G 20/3
MAGNETIZATION AND MAGNETIC ANISOTROPY OF TBFE2, DYFE2, TB0.27DY--ETC(U)
JAN 79 A E CLARK, R ABBUNDI, W R GILLMOR
NSWC/WOL/TR-79-17

UNCLASSIFIED

NL

| OF |
AD
A068 615



END
DATE
FILMED

6--79
DDC

14
NSWC/NOL
NSWC/TR-79-17

LEVEL

12

NOL

AD A068615

6
MAGNETIZATION AND MAGNETIC ANISOTROPY OF
TbFe₂, DyFe₂, Tb_{0.27}Dy_{0.73}Fe₂ AND TmFe₂

10
BY A. E. CLARK, R. ABBUNDI W. R. GILLMOR
RESEARCH AND TECHNOLOGY DEPARTMENT

11
9 JANUARY 1979

12 10p.

DDC
RECEIVED
MAY 15 1979
RECEIVED
C

Approved for public release, distribution unlimited

16 RR02206

17 RR02206-1

DDC FILE COPY



NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448 • Silver Spring, Maryland 20910

79 05 10 086

391596

13

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSWC TR 79-17	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Magnetization and magnetic anisotropy of $TbFe_2$, $DyFe_2$, $Tb_{0.27}Dy_{0.73}Fe_2$ and $TmFe_2$		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. E. Clark, R. Abbundi and W. R. Gillmor		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center White Oak, Silver Spring, MD 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61152N; RR U2-206; RR 02- 206-01; R34AC
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 9 January 1979
		13. NUMBER OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Published in IEEE Transactions on Magnetics		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Magnetostriiction, Rare Earth		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Saturation magnetizations were measured on single crystals of $TbFe_2$, $DyFe_2$, $Tb_{0.27}Dy_{0.73}Fe_2$ and $TmFe_2$. Over most of the temperature range from 4 K to 300K, these values are substantially larger than those measured earlier on polycrystals. The intrinsic magnetic anisotropies, K_1 (O)'s, as determined from magnetic fields required for saturation, are huge ($\sim 5 \times 10^8$ erg/cm ³). For these highly magnetostriictive compounds, the magnetoelastic contribution to the anisotropy, $\frac{1}{2} \frac{dK_1}{d\epsilon}$, is a significant fraction of the total anisotropy.		

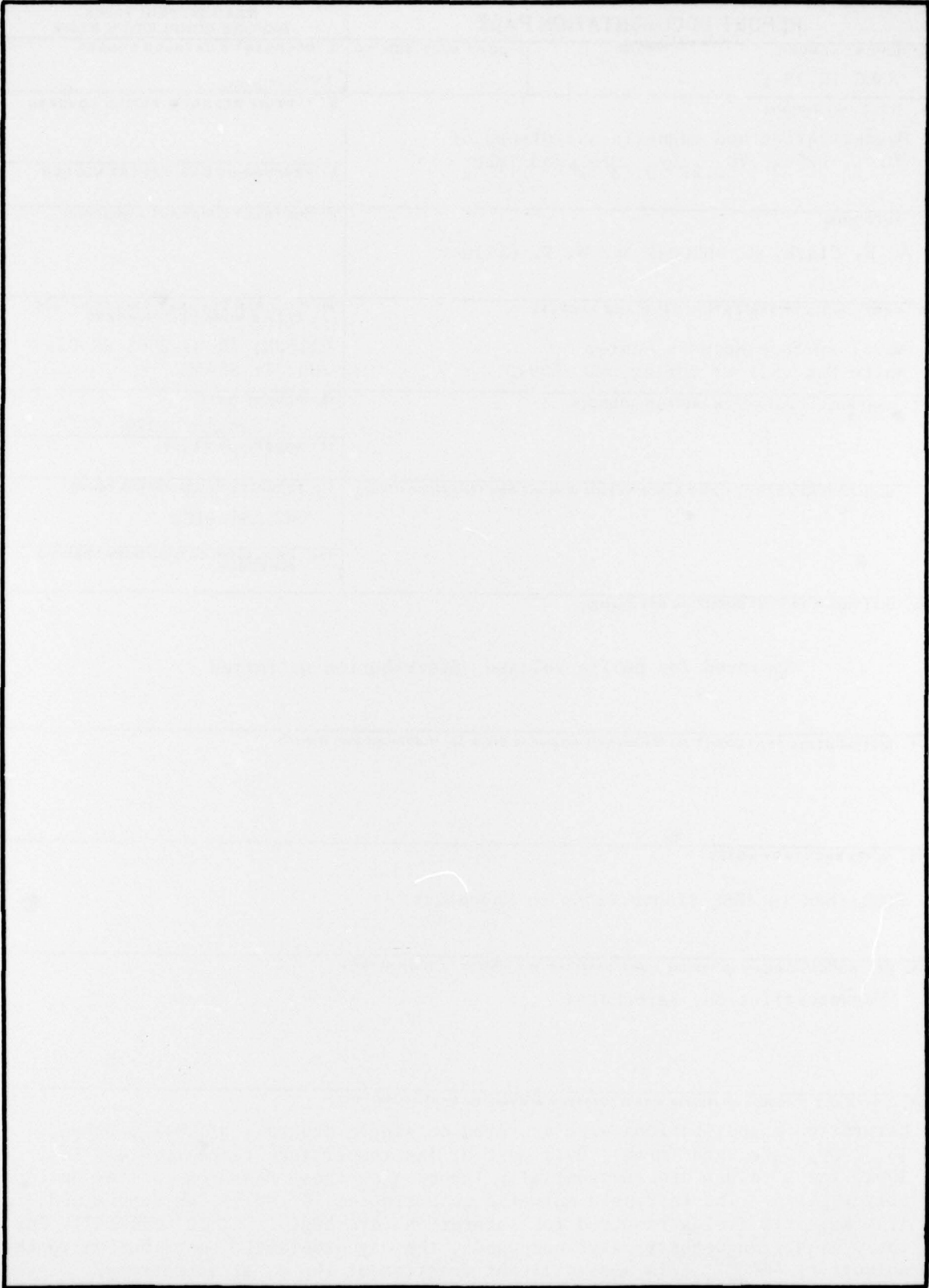
DD FORM 1473
1 JAN 73EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

SUMMARY

In this report are presented saturation magnetization measurements on single crystal TbFe_2 , DyFe_2 , $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ and TmFe_2 . These compounds are strongly magnetic, highly magnetostrictive, and possess a wide range of cubic magnetocrystalline anisotropy, K_1 - ranging from the largest known ($5 \times 10^8 \text{ erg/cm}^3$) for TbFe_2 to a small value ($<10^6 \text{ erg/cm}^3$) for the compensated $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ compound. From the magnetization vs. field measurements along the principal axes, the magnetic anisotropy was calculated as a function of temperature for DyFe_2 and TmFe_2 . It was discovered that, even in the noncompensating compounds, the magnetoelastic contribution to the magnetic anisotropy ($\Delta K_1 = -\frac{1}{2}C_{44} \lambda_{111}^2$) is a significant portion (~ 20%) of the intrinsic anisotropy constant, K_1 . For the case of the compensated $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ compound, the temperature dependence of the magnetomechanical coupling factor was correlated to the temperature dependence of the anisotropy field.

This study was carried out in the Solid State Branch of the Radiation Division as part of the research program on magnetostrictive materials. The research was sponsored by the Office of Naval Research (PO 4-0081, NR 039-110) and the NSWC Independent Research Funds.

Paul R. Wessel
PAUL R. WESSEL
By direction

ACCESSION for	
NEIS	Write Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	
DISSEMINATION	
BY	
DISTRIBUTION/AVAILABILITY	
and/or	
A	

MAGNETIZATION AND MAGNETIC ANISOTROPY OF TbFe_2 , DyFe_2 , $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ and TmFe_2 †

A. E. Clark, R. Abbundi and W. R. Gillmor*

ABSTRACT

Saturation magnetizations were measured on single crystals of TbFe_2 , DyFe_2 , $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$, and TmFe_2 . Over most of the temperature range from 4 K to 300 K, these values are substantially larger than those measured earlier on polycrystals. The intrinsic magnetic anisotropies, $K_1(0)$'s, as determined from magnetic fields required for saturation, are huge ($\sim 5 \times 10^6$ erg/cm³). For these highly magnetostrictive compounds, the magnetoelastic contribution to the anisotropy $-c_{44}\lambda_{111}$ is a significant fraction of the total anisotropy.

INTRODUCTION

The rare earth-Fe₂ Laves phase compounds possess the largest known cubic anisotropies. At low temperatures, anisotropies of DyFe_2 and ErFe_2 exceed 5×10^6 erg/cm³; at room temperature, anisotropies of TbFe_2 and DyFe_2 exceed 2×10^6 erg/cm³. The RFe₂ compounds also possess huge magnetostrictions, which also extend to room temperature for TbFe_2 and SmFe_2 . In this paper we report magnetization measurements on single crystals of TbFe_2 , DyFe_2 , $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ and TmFe_2 . From measurements along the hard magnetic directions, magnetic anisotropy energies are calculated. In magnetostrictive materials, the magnetic anisotropy depends upon the state of strain—a clamped sample possessing the conventional intrinsic anisotropy, described e.g. by K_1 ; a sample allowed to freely strain possessing an additional contribution ΔK_1 arising from the magnetoelastic energy. Even though a large number of materials possess relatively large magnetostrictions, only in a few materials, e.g. $\text{Tb}_2\text{Fe}_{17}$, $\Delta K_1 > K_1$. As part of this paper we report the magnetic properties of $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$. This pseudobinary compound, synthesized from highly magnetostrictive TbFe_2 and DyFe_2 , has the proper rare earth ratio to compensate the total magnetic anisotropy constant (K_1^{tot}) near room temperature while at the same time maintaining a large magnetostriction. Hence near room temperature, ΔK_1 and the intrinsic contribution K_1^{int} individually are large, but their sum $K_1^{\text{tot}} = K_1^{\text{int}} + \Delta K_1 = 0$.

MAGNETIZATION AND MAGNETIC ANISOTROPY

The magnetizations of polycrystal TbFe_2 , DyFe_2 and TmFe_2 have been known for some time.^{4,5,6} Measurements on single crystal DyFe_2 at low temperatures were reported earlier.⁷ Because of the huge magnetic anisotropies of the RFe₂ compounds, magnetization measurements made on polycrystals using conventional laboratory fields do not yield the true saturation magnetic moments. Fields greater than 100 kOe are necessary to saturate the heavy rare earth compounds TbFe_2 through TmFe_2 .

Single crystals of TbFe_2 , DyFe_2 , $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ and TmFe_2 were grown by O. D. McMasters by horizontal zoning and Czochralski techniques. The magnetic moments of these crystals were measured from 4 K to above their Curie temperatures (except for TbFe_2) utilizing a vibrating sample magnetometer. In Fig. (1-4) the magnetic moments measured along their respective easy axes are compared with the earlier values of Burzo measured on polycrystals. In all cases, the moments of the single crystals are substantially higher. In the heavy RFe₂ series, the rare earth-iron exchange energy de-

creases with increasing rare earth atomic number approximately according to $[(g-1)J(J+1)]^{1/2}$.⁸ Thus for TmFe_2 , with a weak R-Fe exchange, the rare earth sublattice magnetization decreases rapidly with increasing temperature, falling below that of the iron sublattice near 235 K. For TbFe_2 and DyFe_2 , the exchange interaction is much stronger, leading to much higher moments, anisotropies and magnetostrictions at room temperature. In Table I we list the saturation values of the moment at 0 K and 300 K, the theoretical densities and the iron moments calculated assuming $\mu_R = gJ\mu_B$.

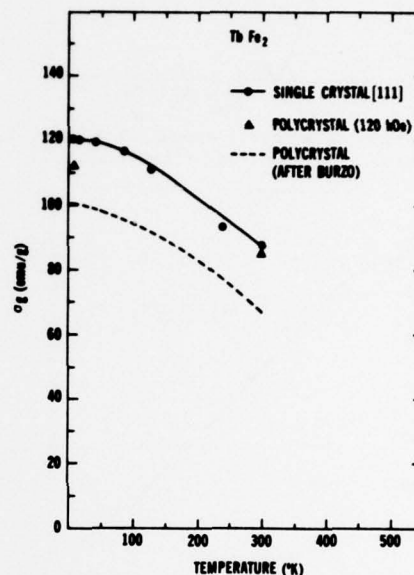


Fig. 1 Spontaneous magnetic moment of a TbFe_2 single crystal as a function of temperature.²

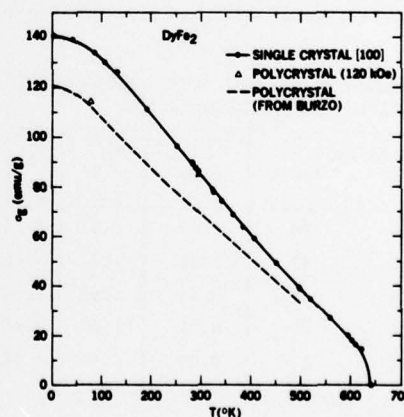


Fig. 2 Spontaneous magnetic moment of a DyFe_2 single crystal as a function of temperature.²

Manuscript received April 4, 1978.

† Supported by the Office of Naval Research & NSWC Independent Research Funds.

* Naval Surface Weapons Center, White Oak, Silver Spring, Maryland 20910

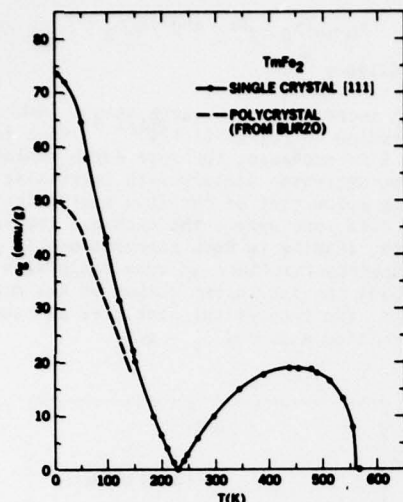


Fig. 3 Spontaneous magnetic moment of a TmFe_2 single crystal as a function of temperature.

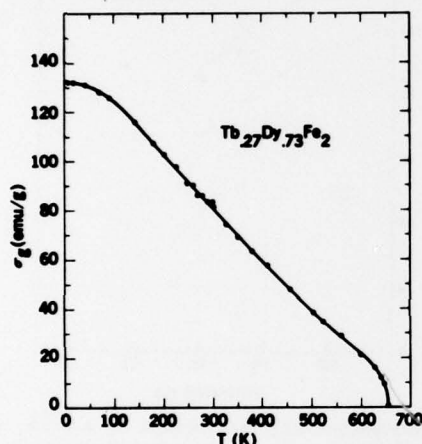


Fig. 4 Spontaneous magnetic moment of a $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ single crystal as a function of temperature.

TABLE I. MAGNETIC MOMENTS, THEORETICAL DENSITIES AND CURIE TEMPERATURES OF RFe_2

RFe_2	σ (emu/gm) 0 K*	σ (emu/gm) 300 K	ρ_t gm/cm ³	$n_{\text{bFe}}^{(d)}$ 0 K	$n_{\text{bFe}}^{(e)}$ 0 K	T_C K
TbFe_2	120	88	9.06	1.60	1.75	697, 711 ^a
DyFe_2	140	87	9.28	1.57	1.60	635
HoFe_2 ^b	135	64	9.44	1.65	1.55	597, 612 ^a
ErFe_2 ^c	116	29	9.62	1.61	1.60	590, 597 ^a
TmFe_2	74	10	9.79	1.64	1.55	560

* Extrapolated

- Taken from polycrystal data of K. H. J. Buschow and R. P. Van Staple, J. de Physique **32**, C1-672 (1971), and E. Burzo, Z. Angew. Physik **32**, T27 (1971).
- N. C. Koon, unpublished.
- See A. E. Clark, AIP Conf. Proc. **18**, 1015 (1974).
- Magnetic moment per iron atom in Bohr magnetons calculated from single crystal data assuming $n_{\text{bR}} = gJ$.
- Magnetic moment per iron atom in Bohr magnetons determined from Mössbauer spectra. W. E. Wallace, Prog. Rare Earth Sci. Tech. **3**, 1 (1968).

For DyFe_2 , TmFe_2 and $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$, the magnetic anisotropy constant K_1 was calculated from the fields required for magnetic saturation along the [100], [110] and [111] directions. The anisotropy constants K_1 for DyFe_2 and TmFe_2 are plotted in Fig. (5). Except at the very low temperatures, the anisotropy of DyFe_2 is much larger than that of TmFe_2 . The single-ion theory has been successful in fitting the temperature dependence of the magnetostriction of the RFe_2 compounds as well as the anisotropy of ErFe_2 . Here we apply that theory to DyFe_2 and TmFe_2 . It is important to realize that even in the non-compensating RFe_2 compounds, because of the high magnetostrictions, ΔK_1 is not negligible. Taking the magnetoelastic contribution to be $\Delta K_1 = -9c_{44}\lambda_{111}^2/2$ and utilizing the single crystal magnetostriction data published earlier, we arrive at the values shown in Table II. The elastic constant c_{44} is taken to be 4.87×10^{11} dynes/cm² for all compounds. From the measured values of K_1^{int} , the intrinsic anisotropy constants and $\Delta K_1/K_1^{\text{int}}$ are calculated. According to single-ion theories, where J is large and the magnetically induced levels are assumed to be nearly evenly spaced, the expression for the temperature dependence of the anisotropy is given by:

$$K_1^{\text{int}}(T) = K_1^{\text{int}}(0) \hat{I}_{9/2}[\chi^{-1}(m_R(T))]$$

and

$$\Delta K_1(T) = \Delta K_1(0) \hat{I}_{5/2}^2[\chi^{-1}(m_R(T))].$$

Here the small temperature dependence of c_{44} is neglected. $\hat{I}_{l+1/2}$ is the hyperbolic Bessel function of order $l+1/2$ normalized to one at $T = 0$ K; χ^{-1} is the inverse Langevin function and m_R is the reduced rare earth sublattice magnetization. In Fig. (5) we show by the solid line the calculated anisotropy based upon $K_1^{\text{int}}(0)$ of 4.7 and -3.8 ($\times 10^8$ erg/cm³) for DyFe_2 and TmFe_2 , respectively. The values of ΔK_1 of -2.4 and -2.7 ($\times 10^8$ erg/cm³) for DyFe_2 and TmFe_2 were taken from magnetostriction data. We find that with one adjustable constant per compound, $K_1^{\text{int}}(0)$, the fit to the data is within 20% over the temperature range of the experiments. For DyFe_2 , the Dy sublattice magnetization was taken from Mössbauer spectra by Bowden et al.¹² For TmFe_2 , the sublattice magnetization was calculated from the total magnetization reported in this paper less that of the iron sublattice inferred from Bowden et al.¹²

TABLE II. MAGNETOELASTIC AND INTRINSIC CONTRIBUTION TO THE MAGNETIC ANISOTROPY (ergs/cm³).

RFe_2	$\Delta K_1(300)^*$ $\times 10^{-4}$	$K_1^{\text{int}}(300)$ $\times 10^{-4}$	$\frac{\Delta K_1(300)}{K_1^{\text{int}}(300)}$
SmFe_2	-970	---	---
TbFe_2	-1330	-6300	.21
DyFe_2	-350	2450	-.14
ErFe_2	-20	-310	.06
TmFe_2	-9.7	-43	.22

* Calculated from λ_{111} values taken from A. E. Clark, J. R. Cullen, O. D. McMasters and E. R. Callen, AIP Conf. Proc. **29**, 192 (1976) and R. Abbundi and A. E. Clark, J. Appl. Phys. **49**, 1969 (1978).

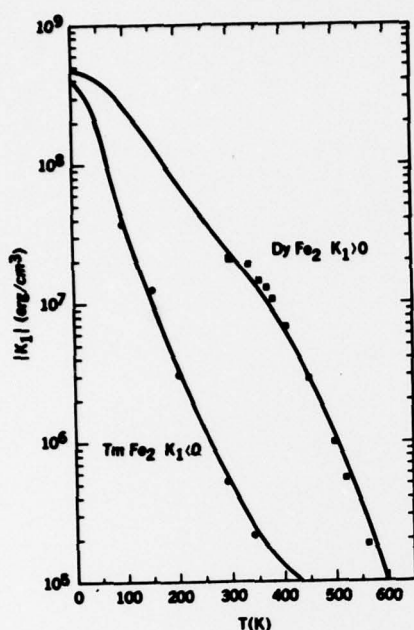


Fig. 5 Anisotropy constant K_1 for single crystals DyFe_2 and TmFe_2 as a function of temperature. The solid curve represents the anisotropy calculated from single-ion theory.

The anisotropy constant K_1 of $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ equals zero near room temperature. K_2 remains negative. The anisotropy is DyFe_2 -like ([100] easy) at low temperatures and TbFe_2 -like ([111] easy) at high temperatures. The fields required for magnetic saturation along the principal directions are shown in Fig. (6). $H_{111} = H_{100}$ at 283 K where $H_{110} = 1.5$ kOe. The anisotropy fields drop rather sharply from very high values at low temperatures. On the high temperature side, the slopes are not so steep, with the anisotropy constant K_1 reaching a peak value of -1.5×10^6 erg/cm³ at 380 K. The rapid drop of the anisotropy constants of both binary TbFe_2 and DyFe_2 over this temperature range accounts for this rather low peak value.

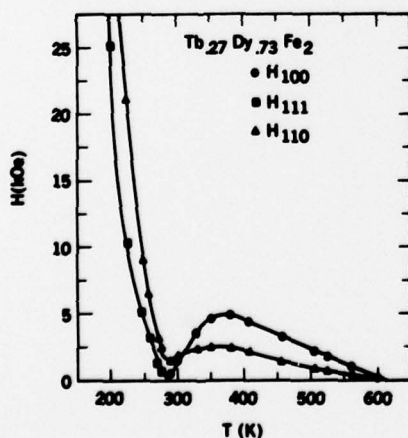


Fig. 6 Fields required for magnetic saturation along the principal crystallographic directions in single crystal $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ as a function of temperature.

Magnetization rotation and domain wall motion can be effected at low applied magnetic fields when the magnetic anisotropy is low. The maximum energy transformed from the magnetic to the elastic systems is $\frac{1}{2} c_{44} \lambda_{111}^2$. Defining $f = \frac{1}{2} c_{44} \lambda_{111}^2 / M H_{110}$ as a figure of merit of magnetostrictive transduction, we calculate for TbFe_2 , $f = 0.016$; and for DyFe_2 , $f = 0.015$. For the pseudobinary $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ compound, $f = 0.5$ with a peak near 283 K. In Fig. (7), we compare $\frac{1}{2} c_{44} \lambda_{111}^2 / M H_{110}$ to the relative magnetomechanical coupling factor k for temperatures near anisotropy compensation (maximum $k = 0.6$). Note that the slightly different pseudobinary composition ($\text{Tb}_{0.26}\text{Dy}_{0.74}\text{Fe}_2$) used for the magnetomechanical coupling measurements shifts the compensating temperature to a little higher temperature. On the low temperature side of the anisotropy compensation, there is a rapid roll-off in both k and $\frac{1}{2} c_{44} \lambda_{111}^2 / M H_{110}$. At high temperature, the roll-off is not as severe, and in fact for k , rather small. The major source of the magnetostrains and the high coupling probably arises from domain wall motion rather than magnetization rotation. Above the anisotropy compensation temperature, the anisotropy remains low enough to prevent domain wall pinning at defect sites.

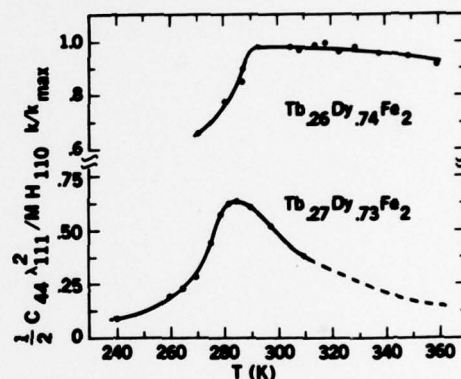


Fig. 7 Comparison of the relative magnetomechanical coupling factor for $\text{Tb}_{0.26}\text{Dy}_{0.74}\text{Fe}_2$ with $\frac{1}{2} c_{44} \lambda_{111}^2 / M H_{110}$ (figure of merit for magnetostrictive transduction) for single crystal $\text{Tb}_{0.27}\text{Dy}_{0.73}\text{Fe}_2$ as a function of temperature.

REFERENCES

1. A. E. Clark, H. S. Belson and N. Tamagawa, Phys. Letters 42A, 160 (1972).
2. A. E. Clark, AIP Conf. Proc. 18, 1015 (1974).
3. S. Iida, Phys. Letters 6, 165 (1963).
4. W. E. Wallace and E. Skrabek, Rare Earth Research II, Gordon & Breach, New York, 1964, p. 431.
5. K. H. J. Buschow and R. Van Stapele, J. de Physique 32, C1-672 (1971).
6. E. Burzo, Z. Angew. Physik 32, 127 (1971).
7. O. D. McMasters, Iowa State University, Ames, Iowa.
8. G. Fischer and A. Meyer, Solid State Comm. 16, 355 (1975).
9. See for example C. Kittel, Rev. Mod. Phys. 21, 541 (1949). Note $\lambda_{100} \ll \lambda_{111}$.
10. S. Rinaldi, J. Cullen and G. Blessing, Phys. Letters 61A, 465 (1977).
11. E. Callen and H. Callen, Phys. Rev. 129, 578 (1963).
12. G. Bowden, D. Bunbury, A. Guimaraes and R. E. Snyder, J. Phys. C: Solid State Phys. 1, 1376 (1968).
13. H. Savage, A. Clark, N. Koon and C. Williams, IEEE Trans. on Magnetics MAG-13, 1517 (1977).

DISTRIBUTION

Defense Documentation Center
Cameron Station
Alexandria, VA 22314

Office of Naval Research
Department of the Navy
800 N. Quincy Street
Arlington, VA 22217
Attn: Code 470
Code 102
Code 470

Commanding Officer
Office of Naval Research
Branch Office
Building 114, Section D
666 Summer Street
Boston, MA 02210

Commanding Officer
Office of Naval Research
Branch Office
536 South Clark Street
Chicago, IL 60605

Office of Naval Research
San Francisco Area Office
760 Market Street, Room 447
San Francisco, CA 94102

Naval Research Laboratory
Washington, DC 20375
Attn: Codes 6000

6100
6300
6400
2627

Naval Air Development Center
Code 302
Warminster, PA 18964
Attn: Mr. F. S. Williams

Naval Air Propulsion Test Center
Trenton, NJ 08628
Attn: Library

12

Naval Construction Battalion
Civil Engineering Laboratory
Port Hueneme, CA 93043
Attn: Materials Division

Naval Electronics Laboratory
San Diego, CA 92152
Attn: Electron Materials
Sciences Division

Naval Missile Center
Materials Consultant
Code 3312-1
Point Mugu, CA 92041

David W. Taylor Naval Ship
Research and Development Center
Materials Department
Annapolis, MD 21402

Naval Undersea Center
San Diego, CA 92132
Attn: Library

Naval Underwater System Center
Newport, RI 02840
Attn: Library

Naval Weapons Center
China Lake, CA 93555
Attn: Library

Naval Postgraduate School
Monterey, CA 93940
Attn: Mechanical Engineering Department

Naval Air Systems Command
Washington, DC 20361
Attn: Codes 52031
52032

Naval Sea Systems Command
Washington, DC 20362
Attn: Code 035

Naval Facilities Engineering Command
Alexandria, VA 22331
Attn: Code 03

Scientific Advisor
Commandant of the Marine Corp
Washington, DC 20380
Attn: Code AX

Naval Ship Engineering Center
Department of the Navy
Washington, DC 20360
Attn: Code 6101

Army Research Office
P. O. Box 12211
Triangle Park, NC 27709
Attn: Metallurgy & Ceramics Program

Army Materials and Mechanics
Research Center
Watertown, MA 02172
Attn: Research Programs Office

Air Force Office of Scientific
Research
Bldg. 410
Bolling Air Force Base
Washington, DC 20332
Attn: Chemical Science Directorate
Electronics & Solid State
Sciences Directorate

Air Force Materials Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Library
Building 50, Room 134
Lawrence Radiation Laboratory
Berkeley, CA 94720

NASA Headquarters
Washington, DC 20546
Attn: Code RRM

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135
Attn: Library

National Bureau of Standards
Washington, DC 20234
Attn: Metallurgy Division
Inorganic Materials Division

Director Applied Physics Laboratory
University of Washington
1013 Northeast Fortieth Street
Seattle, WA 98105

Defense Metals and Ceramics Information
Center
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Metals and Ceramics Division
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37380

Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, NM 87544
Attn: Report Librarian

Argonne National Laboratory
Metallurgy Division
P. O. Box 229
Lemont, IL 60439

Brookhaven National Laboratory
Technical Information Division
Upton, Long Island
New York 11973
Attn: Research Library

Office of Naval Research
Branch Office
1030 East Green Street
Pasadena, CA 91106

Professor G. S. Ansell
Rensselaer Polytechnic Institute
Department of Metallurgical Engineering
Troy, NY 12181

Professor Dieter G. Ast
Cornell University
Department of Materials Science and
Engineering
Ithaca, NY 14853

Dr. E. M. Breinan
United Technologies Corporation
United Technologies Research Center
East Hartford, CT 06108

Professor H. D. Brody
University of Pittsburgh
School of Engineering
Pittsburgh, PA 14213

Dr. S. M. Copley
University of Southern California
Los Angeles, CA 90007

Professor M. Cohen
Massachusetts Institute of Technology
Department of Metallurgy
Cambridge, MA 02139

Dr. R. B. Diegle
Battelle
505 King Avenue
Columbus, OH 43201

Professor B. C. Giessen
Northeastern University
Department of Chemistry
Boston, MA 02115

Dr. G. T. Hahn
Battelle
505 King Avenue
Columbus, OH 43201

Dr. L. A. Johnson
General Electric Company
P. O. Box 8
Schenectady, NY 12301

Dr. J. Perel
Phrasor Technolgy
1536 Highland Avenue
Duarte, CA 91010

Professor O. D. Sherby
Stanford University
Materials Sciences Division
Stanford, CA 94300

TO AID IN UPDATING THE DISTRIBUTION LIST
FOR NAVAL SURFACE WEAPONS CENTER, WHITE
OAK TECHNICAL REPORTS PLEASE COMPLETE THE
FORM BELOW:

TO ALL HOLDERS OF NSWC/TR 79-17
by A. E. Clark, Code R-45

DO NOT RETURN THIS FORM IF ALL INFORMATION IS CURRENT

A. FACILITY NAME AND ADDRESS (OLD) (Show Zip Code)

NEW ADDRESS (Show Zip Code)

B. ATTENTION LINE ADDRESSES:

C.

☐ REMOVE THIS FACILITY FROM THE DISTRIBUTION LIST FOR TECHNICAL REPORTS ON THIS SUBJECT.

D.

NUMBER OF COPIES DESIRED

DEPARTMENT OF THE NAVY
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD. 20910

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, \$300

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DOD 316



COMMANDER
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MARYLAND 20910

ATTENTION: CODE R-45